Full Length Article

Kinematic viscosity of soybean biodiesel and diesel fossil fuel blends: Estimation from permittivity and temperature

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HIGHLIGHTS

- Kinematic viscosity and permittivity of diesel fuel/biodiesel blends were determined.
- The kinematic viscosity of the blends depends exponentially on composition.
- The activation energy of the viscosity of blends depends linearly on composition.
- The viscosity of blends was modelled as a function of permittivity and temperature.
- The model parameters depend only on the properties of the pure fuels.

ARTICLE INFO

ABSTRACT

Kinematic viscosity and relative permittivity were determined in blends of soybean biodiesel with diesel fossil fuel in the full range of composition at temperatures between 298 K and 318 K (±0.1 K).

The kinematic viscosity as a function of temperature fits very satisfactorily to an Arrhenius dependence at all the compositions. The activation energy of this process depends linearly on blend composition. Also, at constant temperature, the kinematic viscosity increases exponentially with biodiesel content.

From the analysis of the experimental data, a model is proposed to estimate the kinematic viscosity of blends of unknown composition as a function of permittivity and temperature. Interestingly, the model parameters depend only on the properties of the pure fuels. The fitting to experimental data is very satisfactory; the RMS uncertainty is lower than 0.02 mm^2 s^{-1}.

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1. Introduction

Biodiesel (BD) is an alternative biofuel used in Diesel engines, normally blended with diesel fossil fuel (DF) [1–3]. The accurate knowledge of the physical and chemical properties of DF/BD blends is very important for the optimization of engine performance. In particular, the determination of the fuel kinematic viscosity is necessary to achieve a proper fuel atomization; this impacts directly on the combustion efficiency and consequently in the engine power [1,4,5]. The standard method of fuel viscosity measurements [6] provides highly accurate results but requires long measurement times and it is not suitable for online measurements. Therefore, alternative or indirect methods that avoid these limitations are of technological interest.

The kinematic viscosity of DF/BD blends strongly depends on temperature and composition, and several numerical models that attempt to describe the viscosity of blends of known composition as a function of temperature are found in the literature [7–11]. However, the determination of the composition of DF/BD blends is not straightforward.

In recent works [12,13], the authors studied in detail the dependence of the permittivity of DF/BD blends on composition and temperature to accurately estimate their composition. Dielectric spectroscopy [2,14,15] is a low cost, non-destructive technique, that is fast, adaptable to online measurements and requires no special training. It has been used to characterize BD [2,16], and fatty

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acid methyl esters (FAME) [17], vegetable oils [18,19], to estimate the composition of DF/BD blends [12,13,20–22], to monitor the biodiesel purification process [23], to distinguish between vegetable oils and biodiesel [24] and to detect contaminants in the final product [25].

In this work, a systematic study of the kinematic viscosity of DF/BD blends was carried out as a function of temperature, composition and permittivity. From these results, a model of kinematic viscosity estimation is proposed with very good fitting to experimental data. This is of interest for the implementation of multiparametric sensors and control strategies.

2. Theory

Several numerical models have been proposed to describe the dependence of viscosity of liquids with temperature. Among them, those based on the exponential dependence that follows from the pioneer works of Andrade and Eyring [26,27] are particularly interesting. Therefore, in this work, we propose that, at a given a composition, kinematic viscosity, η, of DF/BD blends follows an Arrhenius law

$$\eta(T) = Ae^{\frac{E_a}{kT}} \tag{1}$$

where η and A are in mm^2 s^{-1}, T is the absolute temperature (K), E_a is the activation energy in electron volts (eV) and k is the Boltzmann constant (8.617332×10^{-5} eVK^{-1}). This a very reasonable assumption for temperatures well above the pour point and the cold filter plugging point (CFPP).

Furthermore, at each temperature, the kinematic viscosity has been numerically fitted to an exponential dependence on biodiesel content, Bx. Therefore, at a given temperature, the kinematic viscosity of a blend is modeled as

$$\eta(Bx) = Ce^{DBx} \tag{2}$$

where C and D are fitting parameters, and C is given in mm^2 s^{-1} and D in %$^{-1}$. Eq. (2) is similar to one of the empirical models proposed in [8].

As shown in a previous work [13], the permittivity of the blends may be accurately estimated from the permittivity of pure DF and BD:

$$\varepsilon_r(Bx, T) = a + bT + cBx + dTBx \tag{3}$$

where ε'_r is the relative permittivity, T is the absolute temperature, and a, b, c and d are obtained from the permittivites of DF and BD as a function of temperature, as explained in [13].

3. Materials and methods

3.1. Materials

Commercial soybean BD and ultra low sulfur content DF samples were provided by local producers. The samples of BD and DF complied with EN 14214 [28] and ASTM D975-15c [29], respectively. DF/BD blends were prepared in the full range of composition, in 10% steps. In this work, the composition of the blends is given as BD percentage, x, in volume (V/V). For instance, B10 indicates a 10% of BD in the blend.

3.2. Methods

Kinematic viscosity of blends and relative permittivity of pure DF and BD were measured between 298 K and 318 K. The temperature of the samples was controlled within ±0.1 K with a thermostat (Lauda).

Kinematic viscosity measurements were carried out according to ASTM D445 [6] with a Canon Fenske viscometer (Size No. 50). Measurement uncertainty was below 0.1%.

Relative permittivity of pure DF and BD was measured with an RLC meter (Tonghui TH2822C), at the frequencies of 1 kHz, 10 kHz and 100 kHz. Since the differences in the measured permittivity values at the three frequencies were below 1%, the reported results correspond to 100 kHz. From pure BD and DF permittivities, the model of Eq. (3) was applied to estimate the permittivity of their blends ($10\% \leq Bx \leq 90\%$) [13]. The permittivity measurement system is also described in detail in [13]. The calibration uncertainty of the system was below 1%.

4. Results and discussion

4.1. Kinematic viscosity, composition and temperature

Fig. 1 shows experimental data of kinematic viscosity, η, as a function of the temperature, T, and composition, Bx, of all the studied samples. It can be seen that the experimental data define a smooth and regular surface.

Fig. 2 shows the plot of kinematic viscosity data as a function of the temperature, $1/T$. The symbols indicate the experimental values and the curves correspond to the fitting of Eq. (1). In Figs. 1 and 2 the limits of the uncertainty bands are not drawn since they are very small in comparison with the symbols.

Table 1 shows the fitting parameters of Eq. (1), A and E_a, their uncertainties, ΔA and ΔE_a, the RMS uncertainty of the estimation,
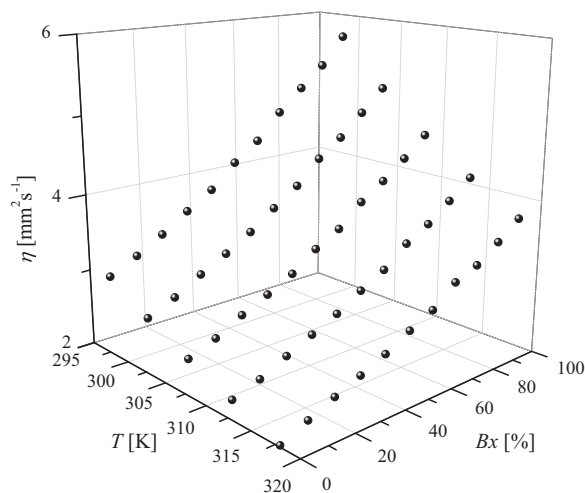

Fig. 1. Kinematic viscosity results, η, as a function of the temperature, T, and composition, Bx.
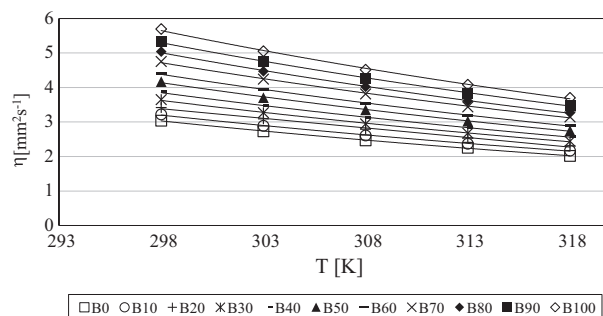

Fig. 2. Kinematic viscosity, η, versus temperature, T. Symbols: experimental values. Curves: fitting of Eq. (1).